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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification [5] : H04L 5/12, H04B 7/02, 7/10	A1	(11) International Publication Number: WO 91/20142
		(43) International Publication Date: 26 December 1991 (26.12.91)

(72) Inventors: JASPER, Steven, C. ; 4370 Haman Court, Hoffman Estates, IL 60195 (US). BIRCHLER, Mark, A. ; 472 Dee Lane, Roselle, IL 60172 (US).

(74) Agents: PARMELEE, Steven, G. et al.; Motorola, Inc., Intellectual Property Dept., 1303 East Algonquin Road, Schaumburg, IL 60196 (US).

(54) Title: MAXIMAL RATIO DIVERSITY COMBINING TECHNIQUE
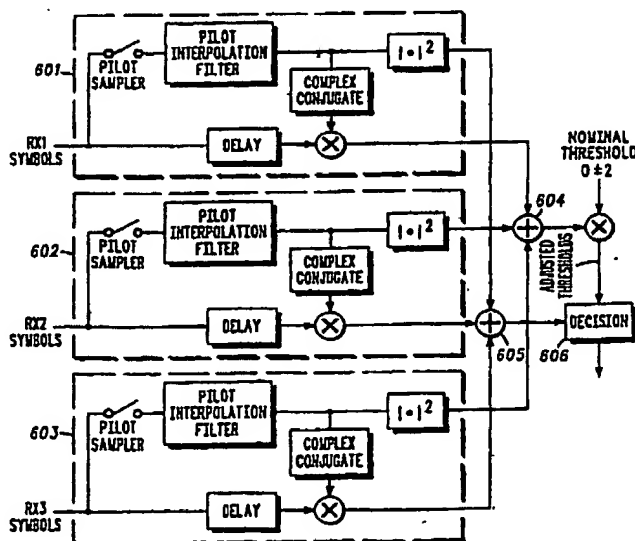
(57) Abstract

A method for implementing diversity reception to counteract effects of channel fading on a transmitted information signal. In diversity receive paths (601, 602, 603), estimates of complex channel gain are computed based upon pilot symbols (201) inserted from time to time in the transmitted information symbol stream (202). Phase corrected and weighted samples from the diversity paths are summed (605) prior to the decision process (606). The squared magnitudes of the diversity path channel gains are summed (604) to provide the proper threshold adjustment.

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MAXIMAL RATIO DIVERSITY COMBINING TECHNIQUE

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Technical Field

This invention relates generally to RF
communication systems, and in particular to a diversity
15   combining technique used to combat the effects of
fading in RF communication systems.

Background of the Invention

20   RF (radio frequency) communication systems are
subject to fading phenomena which produce noise and
distortion in received information signals. One approach
to overcoming the effects of fading is the use of a
diversity receiver system.
25   In a diversity system, more than one receive
antenna is employed. Even if a signal fade occurs at one
antenna, there is a finite probability that a signal of
relatively strong amplitude will still be appearing at one
or more of the other antennas in the diversity system.
30   The use of multiple antennas allows the receiver to
operate on two or more independent versions of the
transmitted signal, and to combine or select these

signals in such a way as to mitigate the effects of fading. The more independent the fading processes associated with each branch, the better the combiner performance.

5   A method well known in the art for combining these branch signals is called maximum ratio combining, or max-ratio. In the max-ratio technique, the branch signals are adjusted so that they are in phase, and then they are weighted in proportion to their individual

10 signal-to-noise ratios before being summed. Of course, in utilizing this technique, a reference of some sort must be established in order to phase compensate the received signals. This reference is commonly established through the transmission of a pilot tone. A

15 pilot tone is simply a signal that is transmitted at a frequency adjacent to the modulated signal, from which the carrier phase and amplitude are estimated. Unfortunately, the use of a pilot tone carries with it the disadvantage of an increase in the required transmission

20 bandwidth, as well as a higher peak-to-average ratio of the transmitted signal. A pilot tone system is also susceptible to decorrelation between the pilot tone and the information bearing signal. This can lead to errors in the phase adjustment and weighting processes.

25   Accordingly, a need arises for a method for max-ratio combining in a diversity system which does not suffer from higher bandwidth requirements nor the decorrelation and peak to average problems associated with the separate pilot tone technique.

30

Summary of the Invention

The above-described need is satisfied through a method for implementing diversity reception to
5 counteract the effects of channel fading on a transmitted information signal. At a transmitter, one or more predetermined pilot symbols are inserted, from time to time, into a quadrature amplitude modulated (QAM) information stream, and an RF carrier is
10 modulated with the QAM information stream to provide a transmitted signal. Within each diversity path of a receiver designed to receive the transmitted information signal, the received signal is demodulated and appropriately sampled to provide a sampled, demodulated
15 signal. The pilot symbol samples and information symbol samples are separated, and the pilot symbol samples are processed at predetermined pilot sample times to determine estimates of complex channel gain at each pilot sample time. Since the information symbol
20 sample rate is higher than the pilot symbol sample rate, the complex channel gains are interpolated to compute complex channel gain estimates for each information symbol sample time.

Each information symbol sample is then multiplied
25 by the complex conjugate of the corresponding complex channel gain estimate to provide a phase corrected and weighted estimate of the transmitted information symbol, where the weighting is approximately the square of the amplitude of the complex channel gain. The square
30 of the amplitude of the estimated complex channel gain is also calculated.

Then, operating on the outputs of the diversity receive paths, the phase corrected and weighted information symbol estimates are summed to provide a diversity combined information symbol estimate. By
5   summing the squares of the amplitudes of the estimated complex channel gains, an estimate of composite weighting factor is derived. Using the composite weighting factor, a set of adjusted decision thresholds is derived, and estimates of the originally transmitted
10   information symbols are obtained through comparing the diversity combined information symbol estimate to the adjusted decision threshold.

Brief Description of the Drawings
15

Fig. 1 illustrates a max-ratio combining technique of the prior art;

Fig. 2 illustrates pilot symbols interleaved with data symbols in a 16-QAM information stream;
20   Fig. 3 is a 16-QAM signal constellation indicating a predetermined pilot symbol;

Fig. 4 is a block diagram of a receiver designed for operation with a 16-QAM system which phase corrects received symbols based on the complex channel gain
25   estimate and achieves symbol detection through adjusted thresholds in the manner taught by the present invention;

Fig. 5 illustrates interpolation of channel gain estimates in between pilot symbol sample times; and
30   Fig. 6 is a block diagram illustrating the maximal ratio diversity combining technique of the present invention with three diversity receive paths.

Detailed Description of the Invention

     A max-ratio combining technique of the prior art is illustrated in Fig. 1 as generally depicted by the number
5   100. A voice signal (102) is applied to a transmitter (101) and the transmitted signal (103) is received over a plurality of diversity paths (104, 105 and 106). Each of these diversity input signals is scaled in a variable gain amplifier (107, 108 and 109) by an amount proportional
10   to each individual signal power to noise power ratio. These diversity signals are adjusted so that they are in phase (co-phased). The co-phasing process in systems of the prior art is generally dependent upon a pilot tone included with the transmitted signal. After these co-
15   phased and weighted diversity signals are summed (110), a detector (111) yields the system's best estimate of the transmitted voice signal at the output (112).

     In a 16-QAM system, as contemplated by the present invention, the frequency domain pilot tone of the
20   prior art is abandoned in favor of a time domain pilot symbol. Fig. 2 illustrates the insertion of pilot symbols (201) in an input data symbol stream (202).

     In a four-level modulation system as contemplated by the present invention, both in-phase and quadrature
25   information symbols may have any one of four possible values. If in-phase and quadrature components are plotted in rectangular coordinates, this results in an array, or constellation as it is often called, of 16 possible values; thus the term "16-QAM." This signal
30   constellation is illustrated in Fig. 3. It is often convenient, in fact, to consider in-phase and quadrature symbols as representing a complex number with the in-

phase axis (which is labelled I in Fig. 3) analogous to the real number axis, and the quadrature axis (labelled Q in Fig. 3) analogous to the imaginary number axis. An arbitrary, although necessarily predetermined, pilot

5   symbol is also indicated in the figure.

Fig. 4 is a block diagram of a receiver path designed to process QAM information symbols and pilot symbols using the method taught by the present invention. The receiver path is generally depicted by the

10   number 400.

It is considered most advantageous to implement the method taught by the present invention in a digital radio system employing a digital signal processor (DSP). This, of course, is not necessary, but it makes the

15   implementation much simpler. Fig. 4 shows a composite down-converted signal centered at DC as the input to a receiver pulse shaping filter (401). The input symbols are then sampled by a symbol sampler (402) at a predetermined rate, then pilot symbols and information

20   symbols are separated and directed along different paths. Pilot symbols are directed along path 403 while information symbols are directed along path 404.

The first element depicted along the pilot symbol path (403) is a pilot sampler (405) which samples pilot

25   symbols at predetermined times. The sampled pilot symbols are then multiplied by the inverse of the known pilot symbol in a mixer (406) in order to determine how the pilot symbols have been affected by the communication channel. The resulting estimate of the

30   channel effect is known as the complex channel gain estimate. A pilot interpolation filter (408) provides estimates of the complex channel gain at the

information symbol sampling times. This interpolation
is necessary because pilot symbols were inserted in the
information symbol stream only at widely spaced
intervals, so the information symbol sampling rate is
5   correspondingly much faster than the pilot symbol
sampling rate.

Turning briefly to Fig. 5, the complex channel gain
is plotted in rectangular coordinates around orthogonal
real and imaginary axes. Fig. 5 illustrates interpolated
10   channel gain estimates between the pilot sample times.

Returning to Fig. 4, information symbols which are
processed through the information symbol path (404),
are first subject to a delay (407) to compensate for
pilot sample processing that occurs in the pilot sample
15   path (403). Each information symbol sample is
multiplied in a multiplier (410) by the complex
conjugate of the corresponding complex channel gain
estimate illustrated in block 409. The phase corrected
information signal, which is an output of the multiplier
20   (410), is still weighted by channel effects. However,
this weighting factor is closely approximately by the
square of the amplitude of the complex channel gain
illustrated in block 411. In a single receiver, the
nominal thresholds predetermined by the four possible
25   information symbol levels are adjusted by multiplication
in a multiplier (412) with the square of the amplitude of
the estimated complex channel gain (411). The phase
corrected information symbols that form the output of
the multiplier (410) are then subjected to a decision
30   process (413) incorporating these adjusted thresholds to
yield a best estimate of the transmitted information
symbol at the output (414).

In practicing the present invention with a plurality of diversity receive paths, the phase corrected and weighted information symbol estimates from separate receive paths (601, 602 and 603 from Fig. 6) are summed
5   in a summer (605) to provide a diversity combined information symbol estimate. An estimate of composite weighting factor is derived by summing the squares of the amplitudes of the estimated complex channel gains in another summer (604). The composite weighting
10 factor is multiplied by the nominal thresholds to derive a set of adjusted decision thresholds, and the diversity combined information symbol estimate which is the output of the first summer (605) is subjected to a decision process (606) utilizing the adjusted decision
15 thresholds to obtain estimates of the originally transmitted information symbols.
        What is claimed is:

Claims

1.   In an RF communication system using
quadrature amplitude modulation (QAM), a method for
5   implementing diversity reception to counteract effects
of channel fading on a transmitted information signal,
the method comprising the steps of:

at a transmitter:
10   (a)   inserting, from time to time, one or
more predetermined pilot symbols into a QAM
information stream;
(b)   modulating an RF carrier with the QAM
information stream to provide a transmitted signal;
15

within two or more diversity receive paths:
(c)   receiving the transmitted signal to
provide a received signal;
(d)   demodulating and appropriately
20   sampling the received signal to provide a sampled
demodulated signal;
(e)   separating pilot symbol samples from
information symbol samples in the sampled demodulated
signal obtained in step (d);
25   (f)   processing pilot symbol samples at
predetermined pilot sample times to determine
estimates of complex channel gain at each pilot sample
time;
(g)   interpolating complex channel gains
30   determined in step (f) to compute complex channel gain
estimates for each information symbol sample time;

(h)   multiplying each information symbol sample by the complex conjugate of each corresponding complex channel gain estimate to provide a phase-corrected and weighted estimate of the transmitted

5   information symbol, where the weighting is approximately the square of the amplitude of the complex channel gain;

(i)   calculating the square of the amplitude of the estimated complex channel gain;

10

then, operating on outputs of said two or more diversity receive paths:

(j)   summing the phase-corrected and weighted information symbol estimates to provide a

15   diversity combined information symbol estimate;

(k)   deriving an estimate of composite weighting factor by summing the squares of the amplitudes of the estimated complex channel gains;

(l)   using the composite weighting factor

20   determined in step (k) to derive a set of adjusted decision thresholds; and

(m)   comparing the diversity combined information symbol estimate provided in step (j) to the adjusted decision thresholds of step (l) to obtain

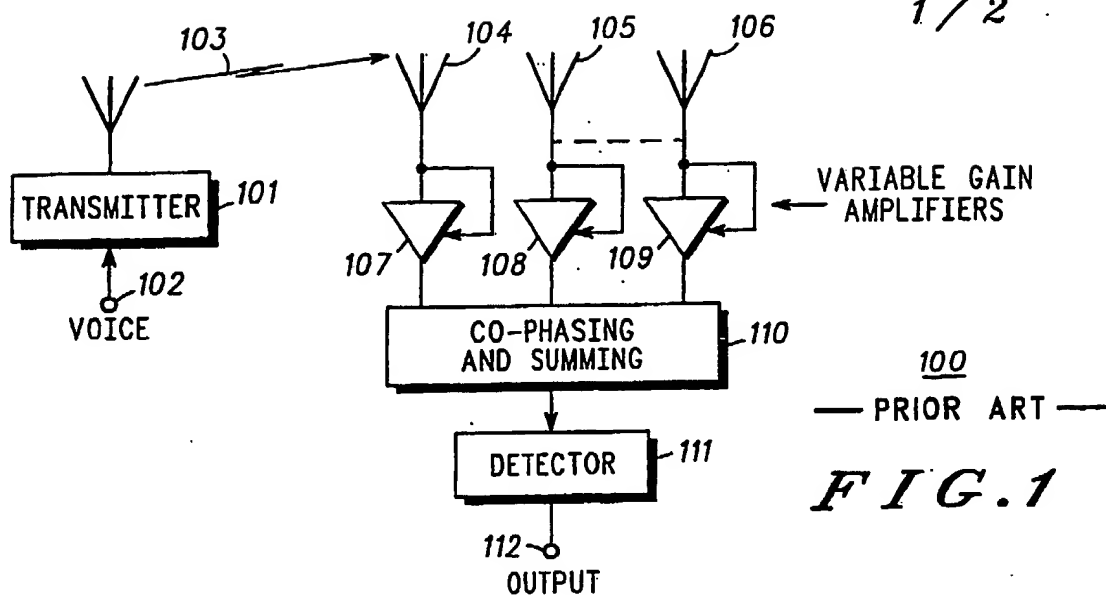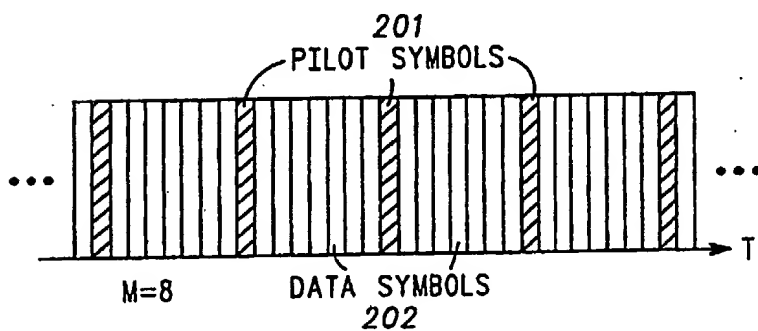25   estimates of the originally transmitted information symbols.

FIG.1

100
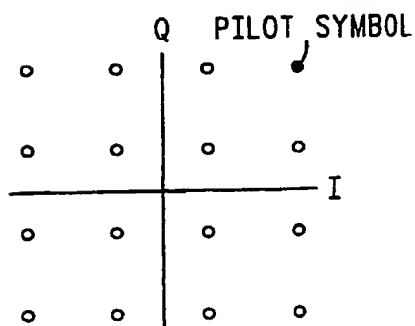— PRIOR ART —

FIG.2

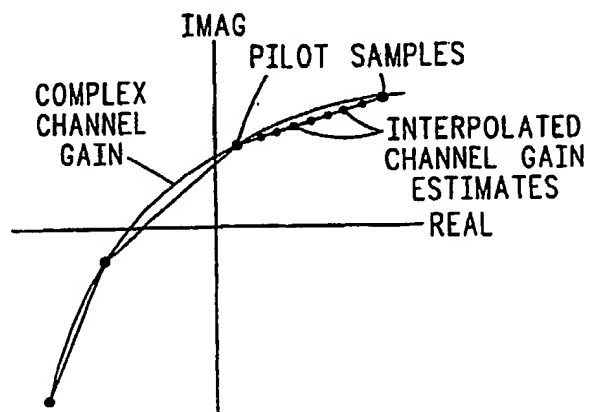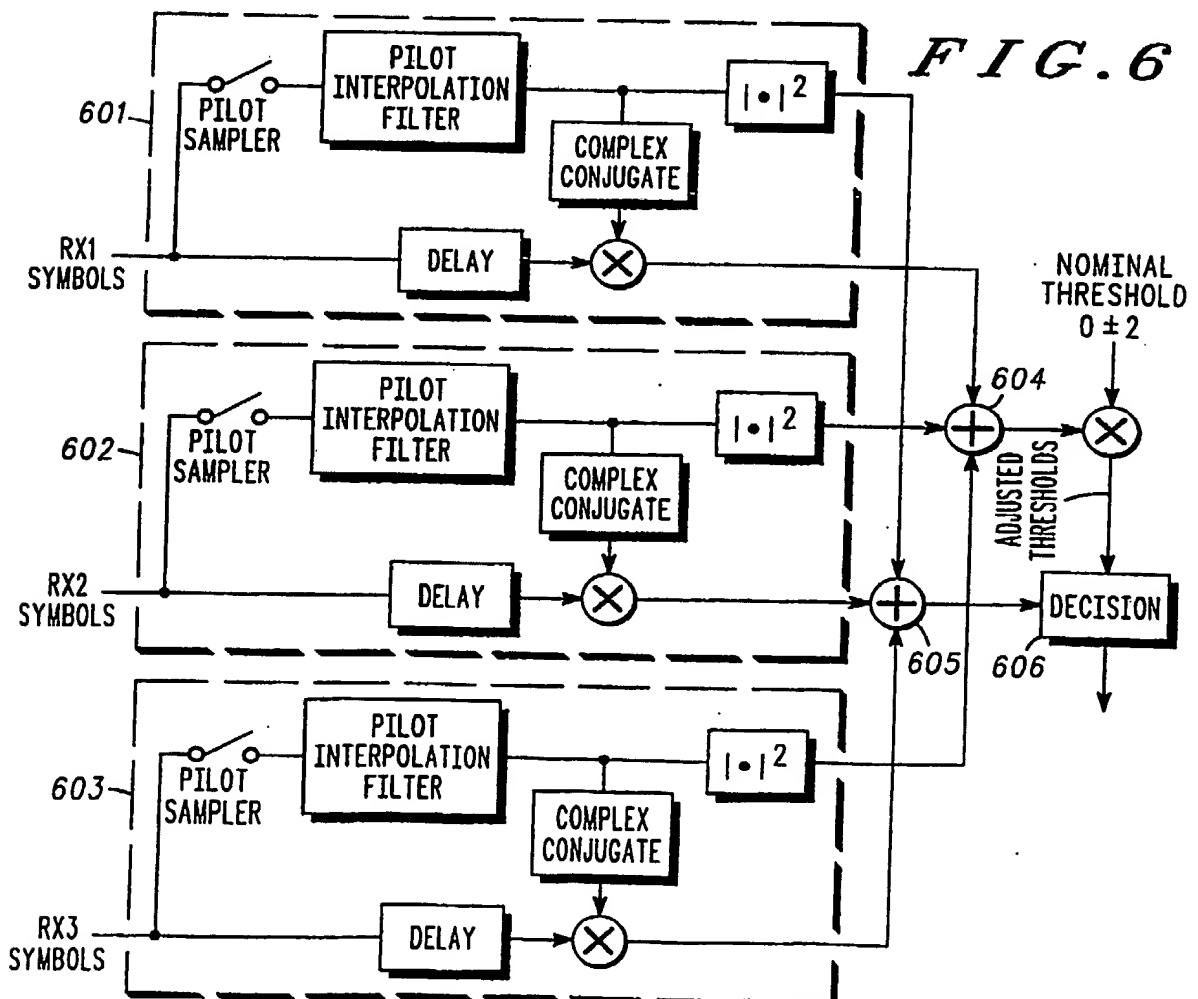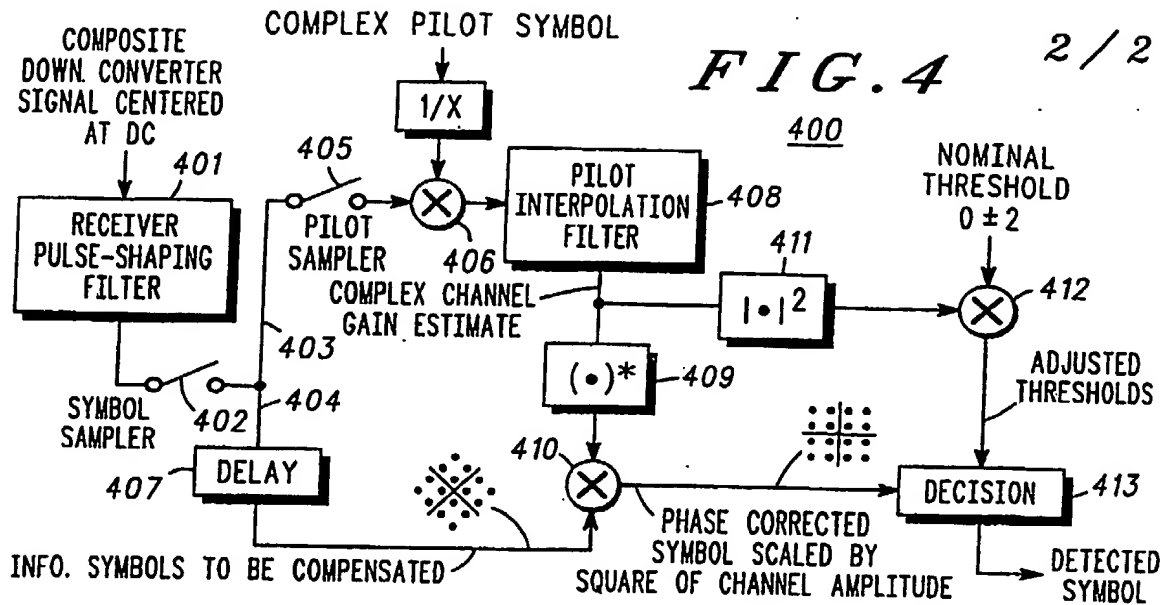*FIG.3*

FIG.5

FIG.4   2/2

FIG.6

INTERNATIONAL SEARCH REPORT

International Application No `PCT/US91/03785`

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC(5): H04L 5/12; H04B 7/02; H04B 7/10
U.S. Cl.: 375/13,14,39,40,98,100,102: 455/52,70,133-137

I FIELDS SEARCHED

Minimum Documentation Searched

Classification System	Classification Symbols
U.S. CL.:	375/13,14,39,40,98,100,102 455/52,70,133-137

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are included in the Fields Searched

III. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A,P	US, A, 4,953,183 (BERGMANS ET AL.) 28 August 1990	1
A	US, A, 4,733,402 (MONSEN) 22 March 1988	1
A	US, A, 4,675,880 (DAVARIAN) 23 June, 1987	1
A	US, A, 4,577,332 (BRENIG) 18 March 1986	1
A	US, A, 3,633,107 (BRADY) 04 January 1972	1

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
19 August 1991	**0 6 SEP 1991**
International Searching Authority	Signature of Authorized Officer
ISA/US	Young T. Tse

NGUYEN NGOC-HO
INTERNATIONAL DIVISION

Form PCT/ISA/210 (second sheet) (May 1986)

FURTHER-INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☒ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers _____, because they relate to subject matter [1] not required to be searched by this Authority, namely:

SEE 210 (EXTRA SHEET)

2. ☐ Claim numbers _____, because they relate to parts of the international application that do not comply with the prescribed require-ments to such an extent that no meaningful international search can be carried out [1], specifically:

3. ☐ Claim numbers _____, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers . . . searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international s____ .._ · ·· · those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search r·µ: ·s rest· ··· ; :. the invention first mentioned in the claims; it is covered by claim numbers:

4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Aut·_ . . . ·. invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (supplemental sheet (2) (Rev. 4-90)

III. DOCUMENTS CONSIDERED TO BE RELEVANT   (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
	Claims 12-21 and 31-42 were not first presented inventions. These has not been searched.	